Coupling damage-sensing particles and computational micromechanics to enable the digital twin: phase II

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Abstract:

Current structural life-management approaches are typically based on empirically-derived estimates of a worst-case scenario. Relying on the worst-case scenarios derived from testing implies that in-service loading conditions are well understood, tails of material behavior distributions are accurately modeled, and coupled damage modes that lead to reduced life are accounted for. Development of such understanding comes at the cost of extensive test programs at the component system scales. Unfortunately, actual in-service loading conditions (usage) and material behavior are not recorded and no validation of these assumptions is made. This management approach results in overly-conservative design, increased uncertainty in reliability estimates, and costly inspection or replacement of parts which likely contain no damage.

By Bayesian inference, it is possible to combine actual usage data with existing prognoses to continually improve reliability projections throughout the service life of a vehicle. However, such a trend can only occur if vehicle-specific characteristics, usage, and NDE findings are recorded throughout the service life. This is due to the fact that no two vehicles in a fleet are equivalent in terms of as-built geometry, material behavior, usage, or environment while in service and, therefore, should not be expected to be equally reliable.

Digital twin is an emerging concept which employs modeling and simulation of the as-built vehicle state, as-experienced loads and environments, and other vehicle-specific history to enable high-fidelity modeling of individual vehicles throughout their service lives. Under this method, each as-manufactured aircraft (or critical components) will be digitally replicated, then managed based on the data gathered from on-board sensors and damage progression simulations. Using the digital twin method, therefore, will preclude the issues related to assuming a worst-case scenario. Furthermore, the close coupling between diagnosis from NDE and continual prognosis from updated simulations will provide better estimates for when inspections should occur and improve reliability for each vehicle individually.

To provide a real-time monitoring capability, sensory particles will be embedded within structural components. Sensory particles are micron-sized pieces of shape memory alloy that, when embedded in a material, can undergo a magnetic and audible phase transformation upon reaching a designed strain. During transformation, sensory particles produce a characteristic acoustic signal when in the presence of a crack, which are then detected and used to triangulate crack location

during flight. Since sensory particles are placed throughout the material, at small scales, damage detection can be made much earlier than with existing sensing technologies.